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ABSTRACT

Part of the Understanding Our Environment project that is designed to engage students in investigating specific environmental problems through concrete activities and direct experience, this unit uses the contemporary dilemma of acid rain as a vehicle for teaching weather and the characteristics of air and atmosphere. The project involves a hands-on activity in which students examine and compare mock rainwater samples from a fictional remote site in the United States. Information gathered and questions raised in the course of this activity are used to examine weather patterns and to discover how weather is a result of the atmosphere's structure and scale. As a follow-up, the global issues of stratospheric ozone depletion and greenhouse warming are introduced. The objectives include: learning about all aspects of the problem of acid precipitation; drawing inferences about how pollutants are transported through the atmosphere; appreciating the processes and characteristics of the atmosphere; understanding how weather is a function of atmospheric processes; investigating the role of airborne particles in cloud formation; and learning about smog, greenhouse warming, and ozone depletion. (JRH)

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UNDERSTANDING OUR ENVIRONMENT

2

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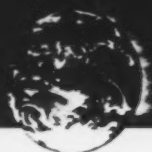


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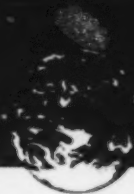
AIR

Michael DiSpezio

This publication is dedicated to Dr. Alan L. McClelland for his many years of devoted work at DuPont, in the government, and in the community to develop and educate people of all ages in mathematics, engineering, and chemistry. His commitment to advancing the understanding of the sciences has influenced thousands of lives and careers around the world.

NTA





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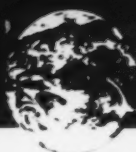
Two transparencies of the NASA/TOMS imagery of the Ozone Hole over Antarctica.

Weather map transparency a from NOAA/NESDIS showing the central United States.

Cover: Infrared images of Hurricane Hugo approaching Charleston, S.C., September 21, 1989. NOAA/NESDIS.

Michael DiSpezio, a former marine biologist and science teacher, is an educational consultant who specializes in the production of educational materials.

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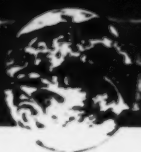


What Have We Done to Our Canopy of Air?

The contemporary dilemma of acid precipitation (and, more generally, acid deposition), is used as a vehicle for teaching weather and the characteristics of air and atmosphere. The project involves a hands-on activity in which students examine and compare mock rainwater samples from a fictional remote site in the United States. Information gathered and questions raised in the course of this activity are used to examine weather patterns and to discover how weather is a result of the atmosphere's structure and scale. As a follow-up, the global issues of stratospheric ozone depletion and greenhouse warming are introduced.

Objectives

- Learn about all aspects of the problem of acid precipitation.
- Draw inferences about how pollutants are transported through the atmosphere.
- Appreciate the processes and characteristics of the atmosphere.
- Understand how weather is a function of atmospheric processes.
- Investigate the role of airborne particles in cloud formation.
- Learn about smog, greenhouse warming, and ozone depletion.



Project Description

Students investigate water acidity in a fictional lake region of the country. Pursuing their mission of finding the source of the acidity (where there are no apparent local candidates), they discover how wind can carry acidic air great distances and they learn to appreciate the complexity of the acid-rain problem. The focus on the "dilemma" of acid rain stimulates their interest in the role of the atmosphere in determining weather. Finally, a study of the large-scale movement of the atmosphere prepares them to consider the concepts of greenhouse warming and stratospheric ozone depletion, two subtler and more global problems of air pollution that threaten the delicate balances of the atmosphere necessary to life.

Background: A Puzzle from the Sixties

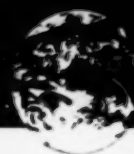
During the 1960s, wildlife biologists noted a decrease in the fish populations and a decline in the general ecology of remote mountain lakes. These freshwater bodies were located in both Scandinavia and the northeastern United States. Tests showed that the lakes contained water that was more acidic than expected.

Factory discharge pipes and other possible local sources of acid effluent were not evident. Instead, the lakes' acidity reflected the acid precipitation that fell on the lakes or entered lakes through runoff.

The acidified rainwater was traced to atmospheric pollutants that were released by the burning processes that were occurring hundreds of kilometers away. Prevailing winds and weather patterns had transported and deposited the acidic products into these mostly unpopulated regions.

The connection between acid-rain damage and industrial activity was observed more than a hundred years ago. In 1862, a newspaper described damage to vegetation in northwestern England. Apparently, sulfur dioxide from factories had acidified moist air. When rain fell, exposed plant parts were damaged.

In 1872, Robert Angus Smith, a chemist who was Britain's first inspector-general of air pollution, described this problem as **acid rain**. At the time, the simplest solution was to build taller chimneys, which only dispersed the pollution farther downwind.



Acid-Base Chemistry

For students to appreciate fully the complexity of the problem of acid rain, it is essential that they understand a few basics of acid-base chemistry. Some preparation in working with acids is also helpful.

All water (aqueous) solutions can be categorized as acidic, basic, or neutral. In its simplest definition, an acid is a substance that (if drinkable) tastes sour and can turn blue litmus paper red. In a water solution, an acid liberates hydrogen ions (H^+). In contrast, a base tastes bitter, has a slippery feel, and turns red litmus paper blue. In a water solution, a base liberates hydroxide ions (OH^-).

The strength of an acid or base is indicated by a pH value. The pH scale ranges from 0 to 14. A pH of 7 indicates that a substance is neutral. The more acidic a substance, the lower its pH value. The more basic (or alkaline) a substance, the higher its pH value. For example, battery acid is a strong acid, with a pH of about 1. Lye is a strong base, with a pH of about 13.

A pH of 7 indicates that a substance is neutral.

Demonstration: A Shiny Old Penny

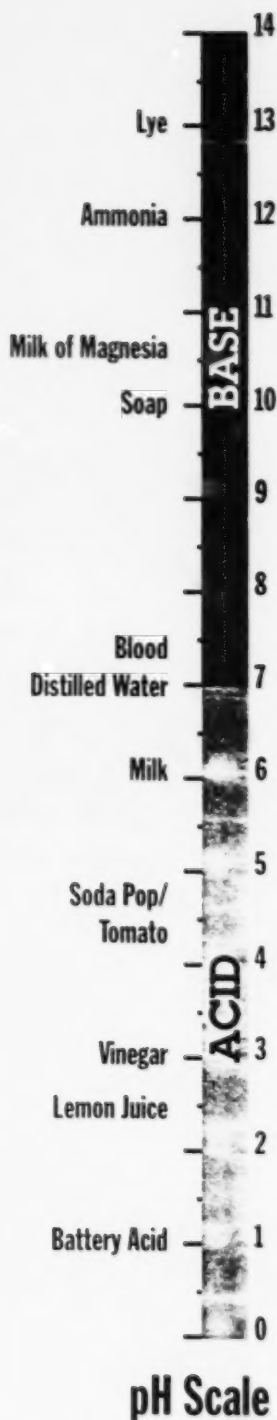
As a general introduction to the effects of acids on substances, supply students with lemon juice. Have them place drops of it on the face of a tarnished penny. After several minutes, have them wipe off the juice and observe the penny's appearance. Connect the observed change to the effect of the acid on the metal's surface.

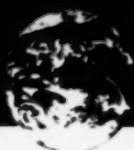
Activity: Acid-Base Indicators

The following activity presents a hands-on experience in which students become familiar with the use of a variety of chemical indicators.

Materials

- pH paper
- Vinegar
- Soda pop
- Blue litmus paper
- Ammonia
- Red litmus paper
- Lemon juice
- Milk of magnesia
- Stirring rods
- Safety goggles





TEACHER'S NOTES : AIR ACID-BASE CHEMISTRY

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Procedure

1. Supply student groups with the chemical indicators and a variety of household solutions as suggested above.
2. Demonstrate the proper transfer technique and use of each indicator substance.
3. Have students identify each substance as an acid or base, measure and record the pH of each substance.

Results: Approximate pH values: lemon juice = 2.5, vinegar = 3, soda pop = 4.5, milk of magnesia = 10.5, ammonia = 12. Tap water pH varies.

Extension: Red Cabbage Indicator

Students can produce their own acid-base indicator using materials found in the kitchen. Tear red cabbage leaves into quarter-size pieces and place them in a small pan. Cover the pieces with water and heat. Allow the mixture to simmer. After about an hour, the water should contain enough cabbage pigment to be used as an indicator solution. Have students compare and contrast the use of this indicator solution with the other indicators they have used in the lab. Are the colors similar?



Red cabbage indicator

Activity: Eating Healthy (Multicultural Connection)

Some groups of Native Americans use blue corn as a staple food. Chemically bound within the corn's kernels is the vitamin niacin. If the corn is eaten directly, niacin will not be released. To unlock the niacin and make the corn easy to handle, the Native Americans soak the dried kernels in a basic solution made from water and wood ashes. The pH of the corn rises to a more alkaline value. Like many plants, blue corn contains a chemical whose color depends on pH. When the wet corn mixture becomes the correct color, a dark gray, the pH is ideal for unlocking the food's niacin.

Supply students with blue cornmeal or blue corn chips. Have them add lemon juice and mix well (or put drops on the chips), and record their observations.

Put a pinch of baking soda in a tablespoon of water. What happens when this solution is added to the corn mixture or dripped on the acidified chips?

Safety Precautions for Working with Acids and Bases

Wear goggles when you are working with solutions. Do not attempt to measure the pH of strong acids (such as battery acid) or strong bases (such as drain-cleaning compounds). If you get any solution on your skin, quickly wash it off with a large amount of water. Students must tell teachers immediately about spilling solutions. Never eat or drink in a laboratory.

Safety Note

Do not taste this cornmeal!



Project: Monitoring the Acidity of Water Samples in a Remote Region

The monitoring project introduces the problem that students will explore throughout the unit. In their first analysis, student groups measure and record the pH of a series of mock rainwater and lake samples from the fictional Otter Lake area. They will discover a range of pH values and a pattern of decreasing pH. Their discovery will lead, later in this unit, to analyzing what harm the higher acidity does and identifying the cause as acid rain. How the precipitation in this remote region became so acid is the question uniting the topics of this unit.

Safety Note

Review the safety precautions for working with acids and bases (page 7).

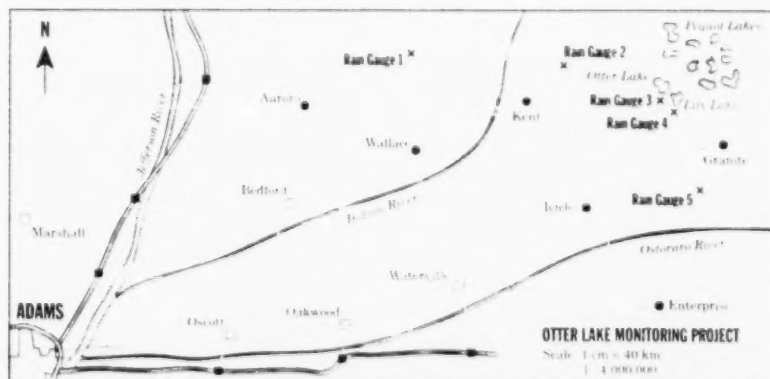
Teaching Notes

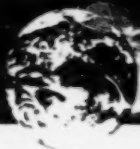
Grouping: Students will work in groups, but each student should receive a copy of the Activity Sheet. You may wish to divide the sites among groups, so that each group does 4 of the 28 measurements and shares the results with the class.

Student Materials: Students can use various methods to determine pH. Electronic pH instruments offer the most accurate and reliable readings. This activity may also be successfully performed using pH paper of appropriate range. If paper with too wide a pH range is selected, students may have to approximate the pH values of the intermediate colors. Even so, this is a good exercise in determining pH with indicator paper.

Answers to "Project"

1. Otter Lake.
2. Samples from rain gauges 3 and 4
3. Samples from rain gauge 1 and 5.





Teacher Preparation

For this activity, you need to make or buy a set of stock solutions to serve as mock rainwater and lake samples. Label each solution with the site and date of collection. The following chart gives the desired pH values.

Sample	1980	1985	1990	1995
Otter Lake	7.0	6.0	5.0	4.0
Lily Lake	7.0	7.0	6.0	6.0
Rain Gauge 1	5.5	5.5	5.5	5.5
Rain Gauge 2	5.5	4.0	4.0	4.0
Rain Gauge 3	5.5	3.5	3.5	3.5
Rain Gauge 4	5.5	3.5	3.5	3.5
Rain Gauge 5	5.5	5.5	5.5	5.5

Make the solutions in quantity to serve 10 groups of students as indicated. (If you are not assigning sites to groups, each group will receive 5 ml of each of the 28 samples listed on the chart.)

pH of 7.0	150 ml
pH of 6.0	150 ml
pH of 5.5	550 ml
pH of 5.0	50 ml
pH of 4.0	200 ml
pH of 3.5	300 ml

Stock solutions should be made with the dropwise addition of 1 molar hydrochloric acid (30-40 drops) to the volume of water indicated. Remember, unbuffered solutions like these change pH with time, so use the solutions as soon as possible. Test pH just before using. If too acidic, add 1 M sodium hydroxide, dropwise.



Analysis of Data

Review the map of the Otter Lake Monitoring Project and, if asked, identify the outline in the lower left corner as an industrial city. After students finish their testing, encourage them to examine and critically analyze the data they have collected. Questions such as the following will help stimulate class discussion: Are any trends evident? How do the changes in Otter Lake and Lily Lake compare? What might account for the observed differences in pH? Is high or low pH a problem? Have students compare the lake and rainwater samples and analyze the differences.

Students will conclude that acid rain is a factor. In the discussion they will uncover connections among wind direction, the sources of pollution, and distribution of acid precipitation. Have students brainstorm sources of acid rain and list possible reasons for the observed changes in acidity in this region. Have them write their ideas on the Activity Sheet or in journals, and set these aside. They will return to this project later.



Discussion/Activity: The pH of Normal Rainwater

Explore the absence of neutral or basic rainwater samples. (A pH of 7 is neutral.) Have each student formulate a hypothesis that explains why all the rainwater (but not lake) samples in the monitoring project had a pH below 5.6.

Next, explain that all rainwater (even if *not* polluted) is slightly acid. Atmospheric carbon dioxide dissolves in rainwater and produces carbonic acid, which accounts for "normal" rainwater's acidic pH. (Recall that pure water has a pH of 7.) Carbonic acid is a weak acid, and "normal" rainwater has a pH of about 5.6. Below that pH, rain is considered acidic.

Students can observe the acidity of carbonic acid by measuring the pH of club soda, which contains dissolved carbon dioxide. Like the carbon dioxide in rainwater, this carbon dioxide produces a solution that is slightly acidic. (Carbonic acid gives soda pop its bite.)



Extension: Acidifying a Neutral Solution

The following activity gives students an opportunity to observe a shift in pH caused by the addition of acid. Help students understand the connection between this activity and the analysis of mock data in the project.

Materials

- pH paper
- Stirring rod
- Distilled water
- Vinegar
- 100-ml beaker
- Safety goggles

Procedure

1. Supply student groups with the materials.
2. Have the groups fill the beaker with distilled water, and measure and record the water's pH.
3. Have the groups add several drops of vinegar to the water, stir well, and remeasure and record the pH.

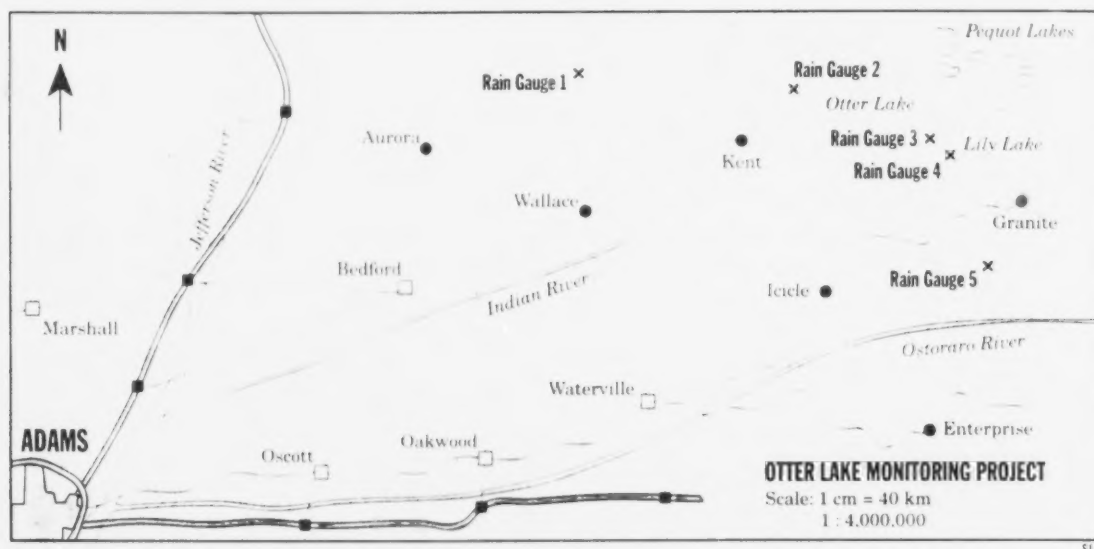
Safety Note

Review the classroom safety precautions for working with acids and bases (page 7).



Project: Monitoring the Acidity of Water Samples in a Remote Region

You are in charge of an environmental monitoring station in a remote lake region in the United States. Over the past 2 decades, scientists have been collecting lake and rainwater samples at five year intervals. It is your job to examine the samples, then interpret and critically analyze your findings.



Instructions

The map above shows the locations of the lakes and rain gauges where samples were taken. Your first responsibility is to determine the pH of each sample. After you determine the pH value, record it in the chart below.

Questions

1. Which lake has had the greater change in pH?
2. Which rain-gauge sample contained the most acidic rainwater?
3. Which rain-gauge sample contained the least acidic rainwater?

Sample	1980	1985	1990	1995
Otter Lake				
Lily Lake				
Rain Gauge 1				
Rain Gauge 2				
Rain Gauge 3				
Rain Gauge 4				
Rain Gauge 5				

Safety Note

Observe precautions for working with acids and bases. You must wear safety goggles.



Acid Rain Formation and Effects

Acid particles are produced in the atmosphere by reactions between chemicals and water in the form of vapor, cloud droplets, or raindrops. The major acid-producing chemicals are sulfur dioxide and nitrogen oxides, which are gases.

The acid particles are often carried long distances by wind. Eventually they fall to the ground in the form of acid deposition (precipitation as rain, hail, and snow, and dry deposition of dust and acid particles). The acid pollutants can also permeate mist and fog, bathing vegetation and buildings in moist, acidic air.

Sulfur Dioxide: The Greatest Threat

Sulfur dioxide (SO_2) is released mainly through industrial processes, particularly the burning of fossil fuel. Coal and crude oil often contain high levels of sulfur compounds. When fuel is burned, the sulfur is oxidized and released as sulfur dioxide.

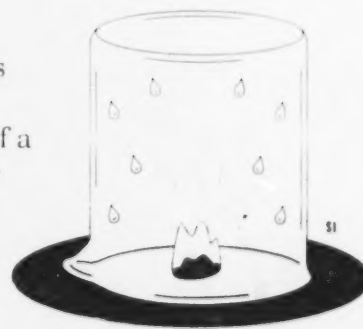
In the atmosphere, sulfur dioxide combines with oxygen to produce sulfur trioxide. This compound reacts with water, forming sulfuric acid in the form of aerosol particles. The reactions can be summarized as follows:

1. The burning of sulfur $\text{S} + \text{O}_2 \longrightarrow \text{SO}_2$
2. The formation of sulfur trioxide $2\text{SO}_2 + \text{O}_2 \longrightarrow 2\text{SO}_3$
3. The formation of sulfuric acid $\text{SO}_3 + \text{H}_2\text{O} \longrightarrow \text{H}_2\text{SO}_4$

Demonstration: Acidic Water

You can demonstrate how sulfuric acid forms by measuring the pH of water exposed to fumes from burning sulfur. Because the fumes are hazardous, this demonstration **MUST** be performed in a fume hood.

Spray some droplets of water on the inner surface of a clean beaker. Measure and record the pH of the water droplets. Place a pea-sized lump of sulfur on a laboratory spoon. Under the fume hood, set the sulfur afire. Invert the beaker and cover the burning sulfur. After several minutes, remove the beaker and remeasure the pH of the water droplets. Explain to students that the water combined with the emissions of the burning sulfur to become acid.



Safety Note
Use fume hood.



Dangerous Fumes (Critical Thinking Exercise)

Ask students how sulfur dioxide fumes can cause serious damage to lungs and to nasal and respiratory tissue.

Some Other Causes

Nitrogen oxides (NO_x) are produced in the fuel-burning processes of internal combustion engines, such as car engines. They also come from fertilizer and from biomass burning. These oxides react with water to produce the corrosive liquid, nitric acid.

Of all pollutants, sulfur dioxide is by far the most common cause of acid rain. In some countries, however, nitrogen oxides cause almost a third of the problem. In a few industrial areas, the release of hydrogen chloride adds a dilute solution of hydrochloric acid to rainwater.

Answer to Dangerous Fumes

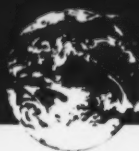
The wet surface of these tissues will react with sulfur dioxide and sulfur trioxide, forming sulfurous and sulfuric acid, respectively. These acids are corrosive, damaging cells and tissues.

Some Effects

Damage to animals and plants. Increased acidity of freshwater lakes and streams can cause fish and other organisms to die. Eggs and larvae are particularly susceptible to increased acidity. Scientists think acid rain damages and weakens trees and other plants.

Structural damage. Acidic solutions, because of their corrosive nature, promote rock weathering and damage buildings. Scientists think acidified air has affected the ancient temples on the Acropolis in Athens more in the past 30 years than in their first 2,400 years of existence. The sandstone and marble of India's Taj Mahal have been similarly affected by gases from an upwind oil refinery that have reacted with this structure's exposed surfaces.

Corrosion of metals. Acidity increases the solubility of hazardous metals like lead, aluminum, cadmium, and mercury. Acidic water percolating through sediments and soil can leach these metals and carry them into groundwater. Acid also accelerates the release of toxic metals from municipal pipes that carry drinking water, and the rusting and weakening of iron bridges.



Demonstration: A Concrete Effect

Remind students that many ancient and modern structures are built of concrete, limestone, and marble, which are susceptible to acidic corrosion. Place several drops of vinegar or dilute hydrochloric acid on a piece of marble. Have students observe the "fizz" of the reaction. Connect their observations to the destruction of buildings and statues.

Discussion: Effects of Acid Rain

Have students discuss why and how acid rain poses a threat to ecology and human health. Mention damage to buildings, forests, and ponds. If you have not already done so, discuss why the presence of acid water is considered a problem in the Otter Lake Monitoring Project.

Activity: Formation of Acid Rain

Distribute copies of the Activity Sheet and review each step of the formation of acid precipitation.

Once airborne, acid-producing chemicals are carried by wind. Chemical reactions, changes of phase, and physical interactions occur among the gases, liquid droplets, and solid particles being transported.

Some pollutant chemicals return to the ground in dry form. Solid particles, including acids in the form of dried powders, can also serve as condensation nuclei at the center of water droplets and ice crystals in clouds.

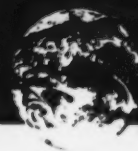
When they finish this activity, students will know about the formation of sulfur dioxide and nitrogen oxides and how they combine with water to produce acid rain. But there are no sources of pollution near the Otter Lake sites. Next, students will look at how wind can move pollutants to sites far from their source, like those in the monitoring project.

Answers to "Acid Rain"

A. 5	F. 4
B. 3	G. 6
C. 9	H. 2
D. 8	I. 1
E. 7	

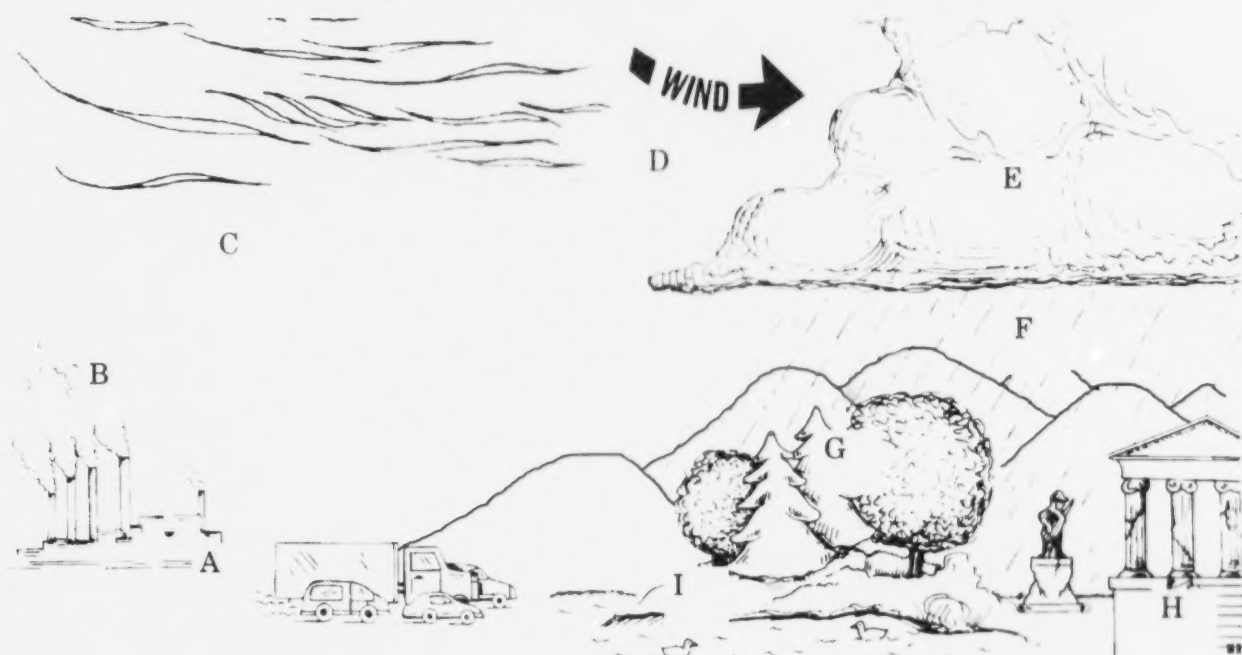
Resource

Kahan, Archie M. (1986) *Acid Rain: Reign of Controversy*. Golden, CO: Fulcrum.



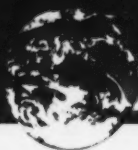
Acid Rain

Read the statements below the diagram. Match the statements to the steps in the formation of acid rain, and write the number for the appropriate statement in its blank box in the diagram.



1. Acid rain creates acid runoff, which flows into streams and lakes and can make them uninhabitable.
2. Acid rain corrodes metal and other materials and dissolves concrete, limestone, and marble, which are often used in buildings.
3. Factories and power plants that burn fossil fuels emit sulfur dioxide and nitrogen oxides.
4. When droplets in clouds become large, they fall as acid rain. Unpolluted raindrops increase in acidity as they fall through air containing acid aerosols.

5. Cars and trucks emit nitrogen oxides in their exhaust.
6. Acid rain can damage plants and change the chemical balance of the soil.
7. Water vapor and acidic vapor condense to droplets on microscopic dust and salt particles, and clouds form.
8. Wind can transport sulfur dioxide, nitrogen oxides, and their atmospheric products hundreds of kilometers.
9. In the atmosphere, sulfur dioxide and nitrogen oxides combine with water vapor to form acidic vapor.



Air and Atmosphere

To learn how pollutants are transported in the atmosphere and deposited at a distant site, we will look at the atmosphere and some of the properties of air.

Layers of the Atmosphere

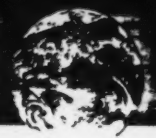
The blanket of air that surrounds our planet is called the atmosphere. The atmosphere is divided into layers that have characteristic properties. (Students should realize that since the layers are somewhat arbitrary, not all sources will agree on altitudes, component gases, and properties.)

Component Gases of the Atmosphere

Remind students that although sulfur dioxide is a hazardous pollutant and helps form acid rain, it is found in only trace amounts in the atmosphere. The major component gases of the atmosphere are nitrogen, 78.1 percent; oxygen, 20.9 percent; argon, 0.9 percent; and carbon dioxide, 0.03 percent. (Percentages are by volume.) Water vapor is also present, but varies from zero to 4 percent, depending on temperature.

Students should envision air as a mixture of molecules of different gases. Some of the gases, such as helium and argon, exist as single atoms. Other gases, such as carbon dioxide and ammonia, exist as molecules formed by reaction between component atoms. Still others, such as oxygen gas (O_2), exist as diatomic molecules. A diatomic molecule is composed of two identical atoms of the same element. Oxygen can also be found in the **triatomic** form, O_3 . Known as **ozone**, this gas in the stratosphere absorbs ultraviolet, or UV, radiation. (In the troposphere, it is a pollutant.)

Nitrogen, the most common atmospheric gas, is an inert diatomic molecule that is changed into a bio-usable form mostly by nitrogen-fixing bacteria in soil. Nitrogen is required by all organisms because it is a component of protein. Oxygen, the second most common gas, is essential to the metabolism of living things. Oxygen is produced by plants during photosynthesis. It is used by both plants and animals during cellular respiration.



Answers to "Composition of the Atmosphere"

1. Nitrogen.
2. Roughly 3.7 times as much nitrogen as oxygen.
3. In the "other gases" category.
4. Because the percentage of water is so variable, it is left out of this generalized representation. (If it were included, all of the other percentages would have to be adjusted in an indeterminate way, using a variable for the water-vapor percentage.)

Answers to

"Layers of the Atmosphere"

1. Troposphere.
2. 20 to 50 km.
3. Mesosphere.
4. Troposphere and stratosphere.

Extension: Atmospheric Chemistry

Creation, reaction, and destruction of atmospheric components can interest students and provide a platform for classroom speakers from universities and government agencies, and for special reports based on current scientific research.

Changing Atmosphere

Students should understand that the atmosphere has changed since Earth formed more than 4 billion years ago. During the early history of our planet, the atmosphere contained no free oxygen. Scientists describe this early atmosphere as a **reducing atmosphere**. As algae, bacteria, and plants evolved, they began to generate oxygen as a by-product of photosynthesis. The oxygen manufactured by vegetation altered the composition of Earth's atmosphere. Over millions of years it became an **oxidizing atmosphere**.

Two Activities: Composition and the Layers of the Atmosphere

Distribute copies of the Activity Sheet "The Atmosphere." These student activities offer experiences in interpreting data and accessing information.

Extension (Art Connection)

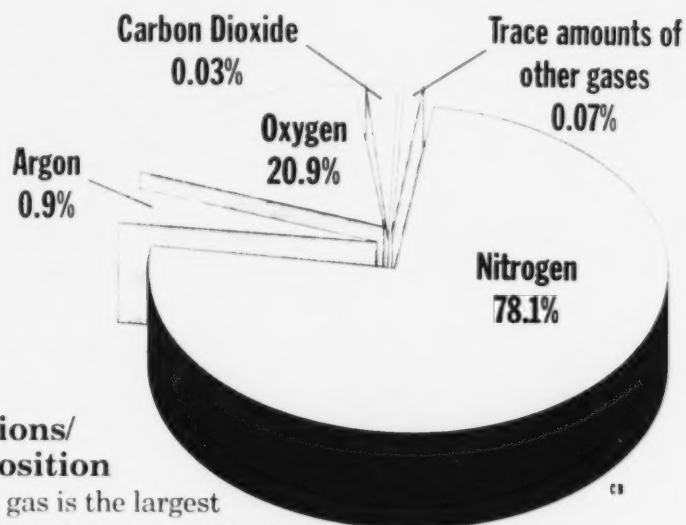
Supply students with shoe boxes and art materials. Have cooperative groups design and construct dioramas that reflect the layered structure of the atmosphere.



The Atmosphere

Interpreting Graphs and Diagrams

Examine the pie graph and the diagram. Then answer the questions that apply to each.



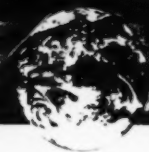
Questions/Composition

1. What gas is the largest component of our atmosphere?
2. How much more nitrogen is there than oxygen?
3. Where would gases such as sulfur dioxide and ozone be placed in this graph?
4. Although the graph does not illustrate it, water vapor is also present in the atmosphere. Its percentage can vary from zero to 4 percent. Why do you think water vapor is not shown?

Questions/Layers

1. In which layer do rain-producing clouds form?

2. Large amounts of UV radiation are absorbed at an altitude of about _____
3. Within the _____, meteors burn up.
4. Jet aircraft release exhaust gases in the _____ and _____.



Properties of Air

Although we cannot see air, we can infer some of its properties. Remind students that two properties used to define matter are (a) it takes up space and (b) it has mass. The following demonstrations and activity allow students to observe these properties firsthand.

Demonstration: Occupying Space

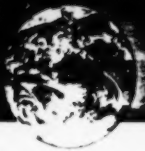
You may begin examining the properties of air by crumpling a sheet of paper. Stuff it into the bottom of a plastic cup. Hold the cup with its mouth facing straight down and submerge it in water. Be careful not to tip the cup. After 10 seconds remove the cup. Ask students if the paper got wet. Then show that the paper remained dry. Challenge them to infer why the paper did not get wet. (The air within the cup took up space, preventing the cup from filling with water.)

Answers to "Having Mass"

Because of the buoyancy effect, the amount of foil added does not equal the added mass of the filled balloon.

Demonstration: Expanding and Contracting

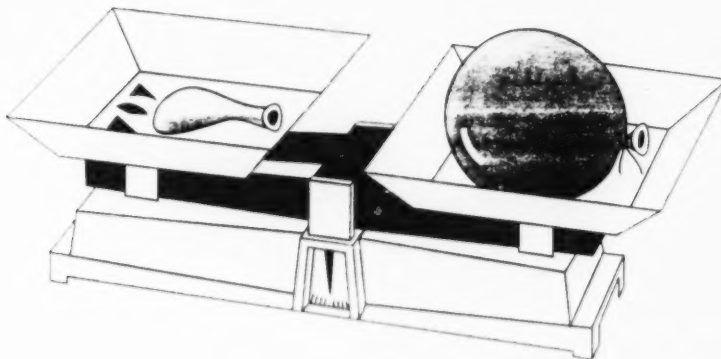
Explain that air, like all gases, expands when heated. To demonstrate, half fill a balloon with air. Use a tape measure to determine its circumference. Immerse the balloon in a beaker of warm water. Wait five minutes and remeasure the circumference. Place the balloon in a beaker of ice water. Wait five minutes and remeasure the circumference. Have students explore the relation between volume and temperature.



Does Air Have Mass?

Materials

- 2 balloons
- Aluminum foil
- Double-pan balance



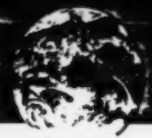
Procedure

1. Place an uninflated balloon in each balance pan.
2. Use small pieces of foil to balance the two sides.
3. Remove one balloon, inflate it, and replace on the pan.
4. Add additional foil to make the sides balance again.

Questions

1. Why is additional mass needed to balance the pans?

2. How does buoyancy affect the filled balloon?



Wind

Wind results from unequal heating of Earth's surface. Air in contact with a heated surface absorbs energy. As air heats, its molecules move faster and farther apart. A warming air mass becomes less dense and rises. As it rises, surrounding, denser air moves down, and replaces the heated air. This and any other natural movement of air is called **wind**.

Answers to

"Air Movement"

1. A spinning motion.
2. Rising or sinking air.
3. From the Sun or Earth. Sunlight coming through windows powers differential heating. Energy for school heating and cooling systems comes from the Sun if the power plant burns fossil fuels or uses solar, wind, or hydro power. It comes from Earth if the plant uses nuclear fuel or geothermal power.
4. Heat released by the warm water produces a rising column of air, which causes the motion.

Convection Cells

Atmospheric air movements are part of **convection cells**. A cell is a complete cycle that begins with rising warm air. As the air goes up, it loses heat and cools. During cooling, air molecules slow down and move closer together. The mass becomes more dense and sinks. When it reaches the ground, it absorbs energy from the heated surface and the cycle continues.

Demonstration: Convection

You can demonstrate convection with a lava lamp, if you can find one. These lamps contain a suspension of liquid components with near-equal buoyancy. The heavier, glob-like components rest at the bottom in contact with the heating element. The lamp takes time to heat, but eventually the heated globs become less dense and rise. When the globs reach the top of the lamp, away from the heating element, they release their heat, cool, become more dense, and sink to the bottom of the lamp. There, they reheat and the cycle starts again.

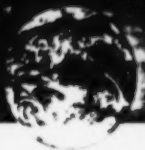
Activity: Air Movement

Distribute a copy of the Activity Sheet "Air Movement" to student pairs, so each will have a spiral. Students should hang the spirals to move freely, preferably over a warm surface (but not over forced air), and record and share observations. Explain that these spirals respond to tiny drafts and that the warm surface (or warm water) supplies rising air to move the spiral. Relate the movement of the spirals to classroom convection cells. Have students compare and contrast these cells to the larger atmospheric cells we associate with wind.

Answers to "Air Movement"

Critical Thinking

1. They are both spiral patterns, one spiral opens in a clockwise direction. The other spiral opens in a counter-clockwise direction.
2. Students may mention advertising, optical illusions, party decorations. Nature has many spirals: climbing vines, sunflowers, snail shells, seashells, to name a few.



Air Movement

Materials

- Scissors
- Thread
- Tape

Procedure

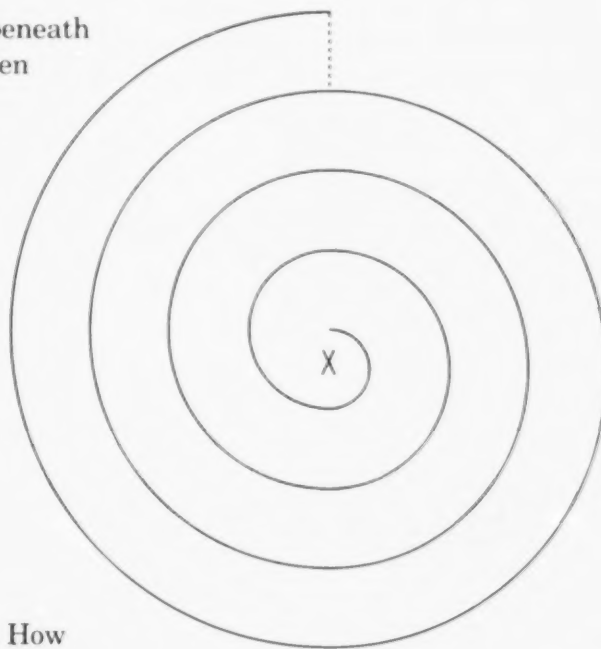
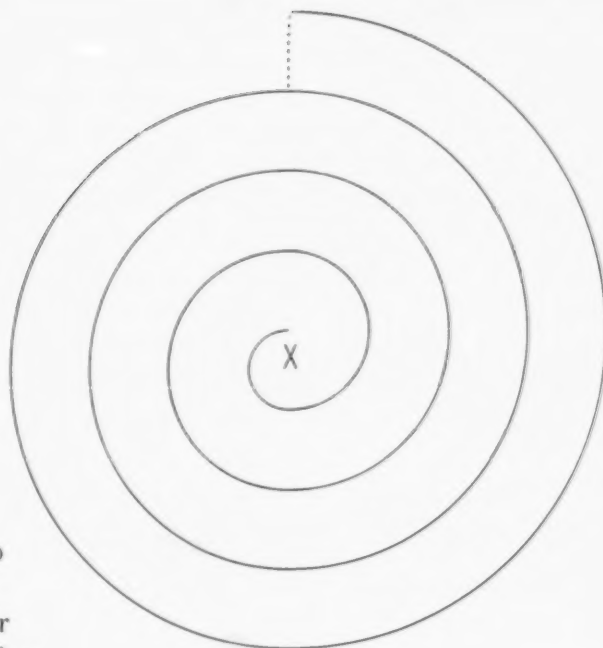
1. Carefully use scissors to cut out each spiral below. When cut, the spiral should open like a coil.
2. Break off a segment of thread about 30 cm long.
3. Tape one end of the thread to the "X" printed in the center of the pattern.
4. Tape the other end of the thread to an overhanging structure such as a doorway arch, underside of a table, or a shelf. Make sure that the spiral is free to rotate.
5. Place a container of warm water beneath the spiral. Wait several moments, then observe the spiral's motion.

Questions

1. What kind of motion do you detect?
2. What causes the spiral to move?
3. Where does the energy responsible for the spiral's movement come from?
4. Why does placing a container of warm water beneath the spiral affect its movement?

Critical Thinking

1. Examine the patterns you cut out. How are they different? How are they the same?
2. Where else have you seen this pattern? What plants and animals have this pattern?





Extension (Art Connection)

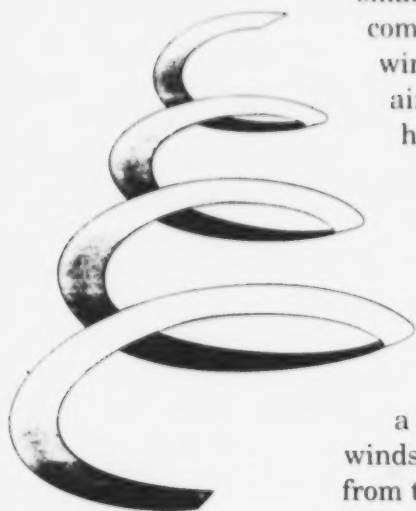
You may wish students to paint or draw patterns on the spirals. The pattern style can be based on the work of artists of other cultures or be simply an original design.

Extension (Technology and Nature Connection)

Student curiosity about how spirals are made and spirals in nature offers an opportunity for outside reading and library research.

Discussion: From Drafts to Global Winds

Use the air spirals as a vehicle for examining large- and small-scale air movements. Challenge students to compare and contrast room drafts with local and global winds. Explain that although they differ in magnitude, air movements are generally created by differential heating of the Earth's surface.



Naming Winds

Winds are named for the direction from which they originate. Therefore, a wind that blows from England toward Norway is called a **southwest wind**. A wind that blows from Newfoundland towards New England is called

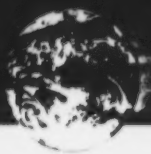
a **northeast wind**. (Storms associated with these winds are called "Nor'easters.") Similarly, wind that blows from the ocean onto the land is called a **sea breeze**, and the opposite, a **land breeze**.

View of a wind spiral from page 23.

Differential Warming

Water and land respond differently to sunlight. If both receive the same amount of solar radiation, the water's temperature will change much less than the land's.

Students who have been to a beach on a hot day have experienced this difference. The sand is often too hot to walk on, but the ocean stays cool. At night, the situation is reversed. The sand becomes cooler than the ocean.

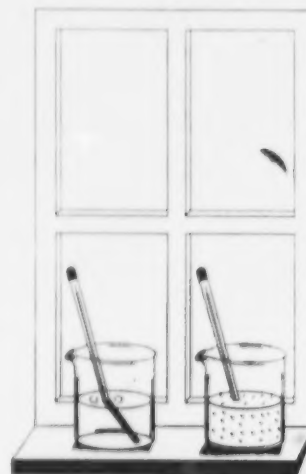


Specific Heat of Land and Water

Differential heating is produced by the characteristic called **specific heat**. The specific heat of a substance is the amount of heat needed to raise the temperature of one gram of that substance one degree Celsius. Water has a high specific heat. It can absorb (or release) a large amount of heat before changing temperature, resulting in a somewhat stable day and night temperature. Land, however, is composed of solid materials that have a much lower specific heat. Just a small amount of heat transfer produces a temperature change. The result is a surface covering that is hot during the day and cool at the night.

Activity: Land Versus Sea

Supply students with a beaker of water and a beaker of sand. Have them determine the starting temperature of the two substances, which should be identical. Place both beakers in direct sunlight for 30 minutes. When students record the temperature, they should discover that sand rose to a higher temperature than the water. This activity can be done with a heat lamp instead of sunlight, or even an incandescent light bulb.

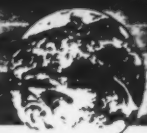


Land and Sea Breezes

A small-scale convection pattern often forms at a land-water interface. During the day, land heats quicker than water and transfers heat to the air above it. As this air rises, the cooler air above the water moves in to fill the gap, creating a breeze that blows from water to land, a **sea breeze**.

During the night, land cools faster than water. Air above the water becomes warmer than air above the land. As this air rises, the air above the land moves in to fill the gap. The air movement creates a breeze that blows from land to water, a **land breeze**.

Similarly, when a valley heats during the day, warm air can move uphill, creating a **valley breeze**. At night, the mountain air cools more than the valley air and descends, creating a **mountain breeze**.



Local and Global Winds

Sea breezes and land breezes are examples of **local winds**. Local winds are caused by variations in local conditions and may blow from any direction. **Prevailing winds** are part of the large-scale pattern of global winds that travel long distances and blow in a consistent direction. The difference in temperature between the cold polar areas and the warm equatorial region sets up convection cells which cause winds to blow from the poles to the equator. (Without the Coriolis effect, there would be a north-south convection current.)

Background: Coriolis Effect

Because of Earth's rotation, winds blowing in the Northern Hemisphere veer to the right in their path. Similarly, winds blowing in the Southern Hemisphere veer to the left. This phenomenon is known as the **Coriolis effect** and it influences the movement of all masses and objects moving freely across Earth's surface, including ocean currents and rockets. (The Coriolis effect breaks up the north-south winds into several smaller currents.)

Two Activities: A Convection Cell and Global Wind Belts

Distribute copies of the Activity Sheet "Differential Heating." Review the formation of convection cells. Have students match the captions to the diagram. Next, identify and describe Earth's global wind belts. Have students write the name of each wind belt at the appropriate latitude. The belts are (from North Pole to South Pole) polar easterlies, prevailing westerlies, northeast trade winds, doldrums, southeast trade winds, prevailing westerlies, and polar easterlies. (Jet streams are not shown.) The prevailing winds are caused by unequal heating of Earth's surface and Earth's rotation.

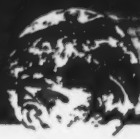
Answers to "A Convection Cell"

First statement: C.

Second statement: B.

Third statement: D.

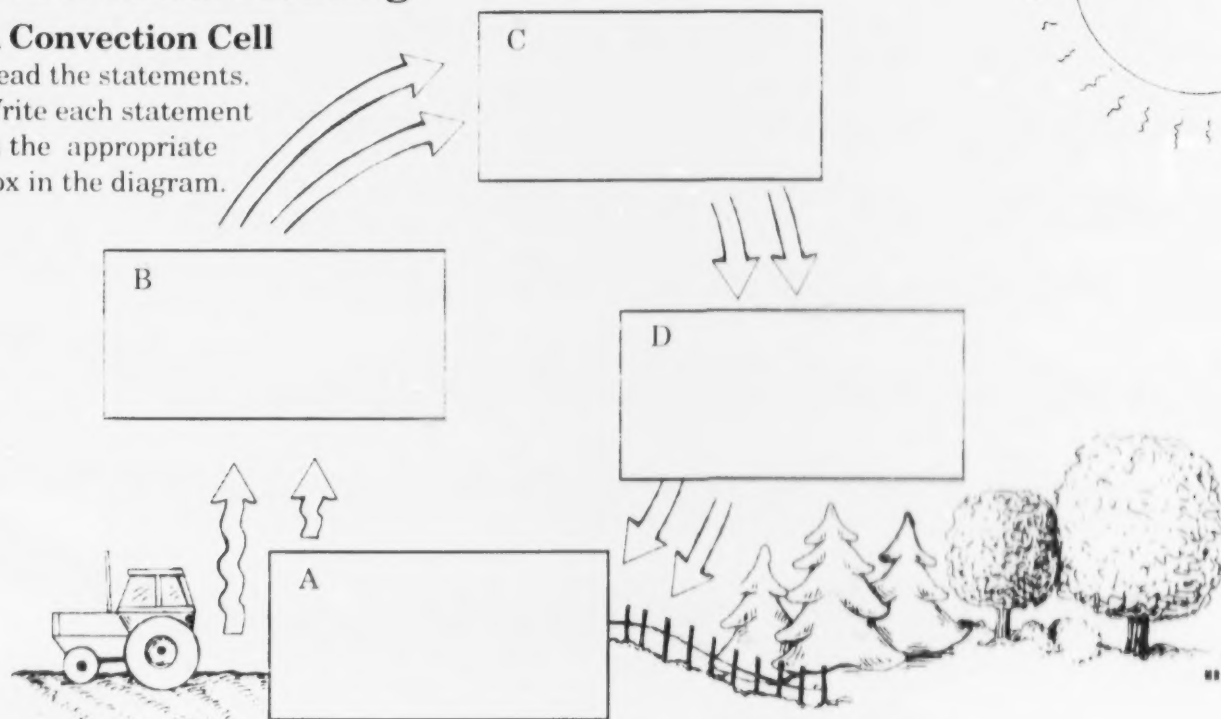
Fourth statement: A.



Differential Heating

A Convection Cell

Read the statements.
Write each statement
in the appropriate
box in the diagram.

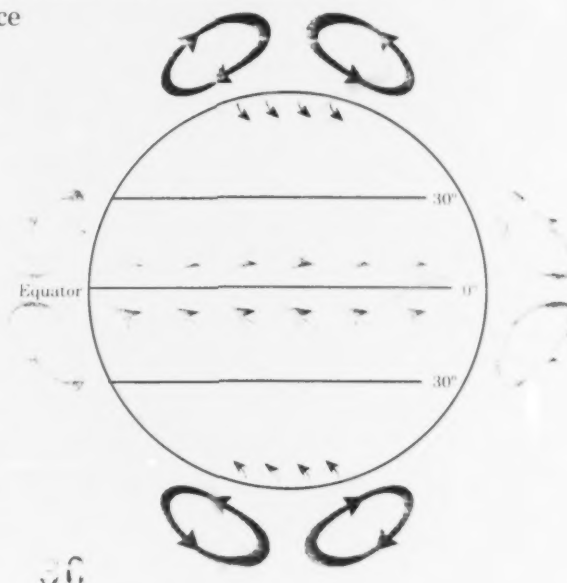


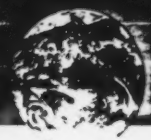
Statements

- Air stops rising and starts to descend when it has cooled and become more dense.
- Air above warmer surfaces heats faster, becomes less dense, and rises.
- Air above cooler surfaces moves to displace warmer, rising air.
- Air in contact with the ground takes up heat.

Global Wind Belts

Label the diagram of the
Earth with the names of
the global wind belts.





Project Revisited

The effect of acid precipitation on lakes and streams was first recognized in the late 1960s. Wildlife biologists noted declining fish populations of lakes and streams in Norway, Sweden, and Finland. Thousands of lakes in remote regions of Scandinavia no longer supported sensitive aquatic life forms. Tests showed that the lake water was acidified.

This evidence is one of the "puzzles" given in the beginning of the unit. (See page 5.) You may wish to present the following material in a similar spirit and also relate the historical example from the 1800s.

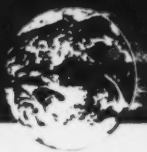


A Scandinavian Discovery (Geography Connection and Critical Thinking)

Identify the United Kingdom, France, Germany, and the Scandinavian countries on a map of Europe. Explain that they are highly industrialized countries that generate much sulfur dioxide and nitrogen oxides.

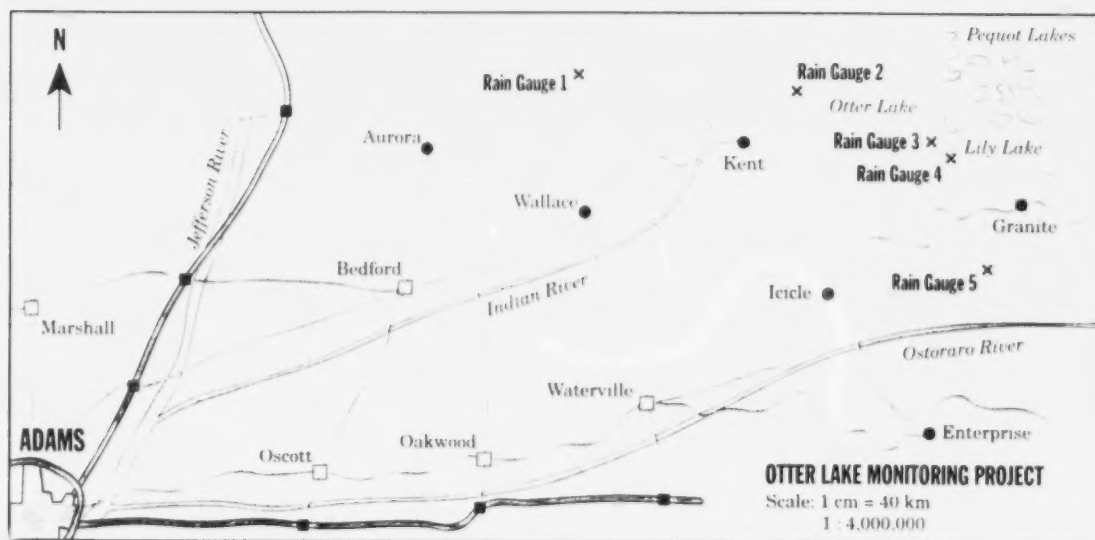
Challenge students to identify a connection between urban emissions in these industrialized regions and the increased acidity in remote Scandinavian lakes.

Students should uncover a connection based on wind and, more specifically, **prevailing wind** direction. Wind blowing from the southwest carries the gases and their products in the atmosphere from the industrial centers to the remote regions of Scandinavia. During this process, various chemical reactions and physical changes take place in the gases, liquid droplets, and the solid particles. The chemicals then fall as acid rain in Scandinavia, lowering the pH of the lakes.



Return to the Monitoring Project

Have students reexamine the map of the Otter Lake Monitoring Project. Challenge them to (a) identify the most likely source of the acid in the precipitation and (b) determine the prevailing wind direction. (If necessary, point out the city, again, in the lower left corner of the map.) Possible sources include the city, a source off the map, and one in the map area but not shown. Most students will choose the city.



A New England Example (Geography Connection)

On a map of the United States, have students locate lakes in remote regions of New Hampshire and Maine. Lakes there have become acidified. Locate industrial centers in Illinois, Indiana, and Ohio. Many of these centers emit more than 100,000 tons of sulfur dioxide each year. Have students infer wind and precipitation patterns. The class should again uncover a prevailing southwest-wind direction.



Weather from the West

Why did all three industrial areas have the same prevailing wind? They are in the same Northern Hemisphere wind belt, the prevailing westerlies.

Much of the United States is in this wind belt, and weather changes usually move from west to east. Students can confirm this by watching television weather forecasts.

The Answer

Identify the area in the bottom left corner of the project map as a city with factories that emit sulfur dioxide; one is a power-generating station that burns fossil fuel.

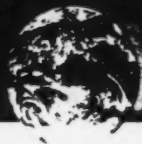
Explain that taller smokestacks are used to release pollutant gases higher in the atmosphere. (Most often, a loftier release disperses emissions farther downwind.) Ask students to consider what might have happened if the source had had a shorter stack.

Sensitive Lakes

Explain that some lakes occur where local geology has a natural buffering action. Acid rain that falls in these regions reacts with the carbonate rocks, soils, and lake sediments and becomes less acidic. Lakes in these regions undergo little, if any, shift in their pH. Many lakes in Canada, Scandinavia, and northeastern United States, especially those with rocky bottoms, have little buffering capability. They are susceptible to the effects of acid rain.

Return to the Project

Have students critically examine the pH values for Otter Lake and Lily Lake. Challenge them to interpret their data as functions of (a) local winds and (b) natural buffering capability of the local geology. (Local winds did not have much effect on the distribution of acid particles. Lily Lake was less affected by the acid rain because the surrounding soil buffers the acid.)



Fossil Fuels

Fossil fuels are formed from the remains of organisms. These organisms contained compounds with sulfur and nitrogen. When fossil fuels are burned, their constituents react with oxygen, releasing large amounts of energy. The combustion also produces carbon dioxide, water vapor, and various other gases, including carbon monoxide, and sulfur oxide and nitrogen oxide.

Discussion or Role-Playing Activity

Announce that the power plant on the project map supplies electricity to several remote towns and their hospital. The plant is aging and the chemical scrubbers in the smokestacks that remove sulfur dioxide from emissions need a costly overhaul. Explain that fossil fuels with a high-sulfur content are less expensive than "cleaner" low-sulfur fuels. Assign the following roles to class members: wildlife biologist, power-company stockholder, worker at the power plant, hospital spokesperson, politician, and local resident. Using role-playing, these individuals should interact in an open forum and discuss what to do (if anything) about the pH findings.

Someone suggests nuclear power as an alternative. She insists that it does not produce acid-generating oxides and therefore cannot harm the environment. Have students research and evaluate her claim.

Extension

Challenge students to propose and investigate solutions to the problem of acid rain. These may include smokestack scrubbers and other chemical filters, low-sulfur fuels, alternate energy sources, controlling automobile emissions, and encouraging use of public transportation.



Air Pressure

Wind and weather are constantly changing. Differences in the density of air masses cause differences in air pressure. Differences in air pressure can be used to predict air movement (wind) and, therefore, weather.

Density and Air Pressure

Cool air is denser than warm air. Because cool air has more molecules per unit of volume, a mass of cool air has greater weight and therefore exerts greater pressure. That is why a mass of cool air is often referred to as a "high-pressure" air mass.

Warm air is less dense than cool air. It has fewer molecules per unit volume, a mass of warm air has less weight and thus exerts less pressure. (Heating air *in a confined space* raises its pressure, because the air is not free to expand and become less dense.)



Activity or Demonstration: Air Pressure

Many students find the results of this simple activity surprising.

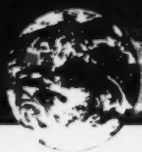
Fill a large pan with a layer of water several centimeters deep. Fill a plastic cup with water, cover the mouth of the cup, and invert the cup in the pan. Carefully lift the cup, but keep its mouth just below the water's surface.

Ask students what they observe. (The cup will remain full, due to the pressure of air on the water outside the cup.)

Measuring Air Pressure

Air pressure can be expressed in different units. Scientists measure air pressure in millimeters of mercury in a column. (You may wish to demonstrate how a barometer works.) At sea level (at 0 degrees Celsius), the standard pressure is 760 mm (29.92 inches).

Meteorologists express air pressure in millibars (mb). One thousand millibars equal one atmosphere of pressure. High-pressure regions have pressure greater than 1,013.2

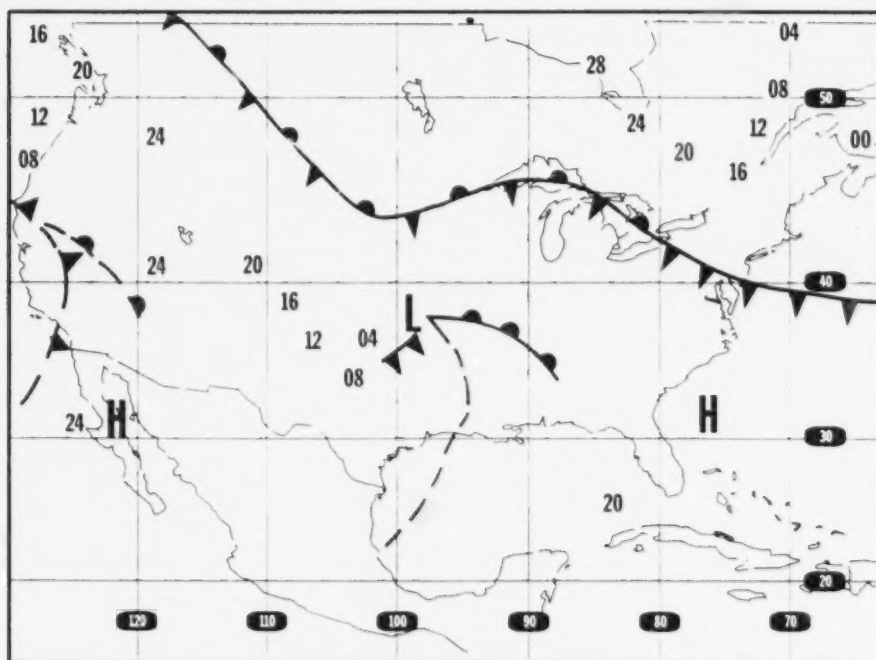


mb; low-pressure regions have less. The millibar is the unit most often used on weather maps.

Isobars, Wind, and Weather Prediction

Isobars are lines on a weather map that connect points of equal pressure. You can learn about wind and weather conditions by examining isobar patterns.

Wind is caused by differences in air pressure. Wind blows from regions of high pressure to regions of low pressure. Isobars show how air pressure is changing. If isobars are close together, the pressure gradient is steep and the wind is strong. The farther apart the isobars, the weaker the wind.



Typical sea level pressure is 1000 millibars (mb). Meteorologists use the convention that 00 represents 1000 mb. Example: 1024 mb is represented by the 24 isobar; 998 mb is represented by the 98 isobar.

▲ low front.

▼ high front.

▲▼ stationary front.

Activity: Interpreting Isobars

Supply the students with weather maps and use the isobar patterns to predict wind direction and relative strength.



Humidity, Clouds, and Rain

In this section, the study of acid rain concludes by investigating clouds, precipitation, and the role of sulfur dioxide and nitrogen oxides in forming smog.

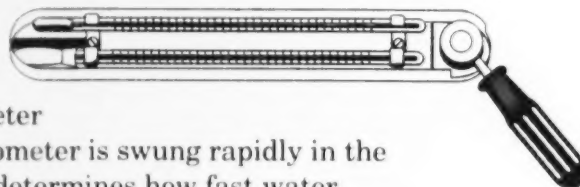
Water Vapor and Humidity

Explain that the atmosphere contains water vapor (water molecules). The amount varies from zero to about 4 percent by volume. **Absolute humidity** is the amount of water vapor in a particular volume of air. How much water vapor air holds depends on the air's temperature and amount of water available. The higher the temperature, the faster water vaporizes, so warm air can hold more water vapor than cold air. **Relative humidity** compares the actual amount of water vapor in an air mass to the amount the air mass could hold.

Measuring Humidity

Several types of instruments are used to measure humidity. Students may be most familiar with the **hair hygrometer**, which depends on moisture's effect on hair length. As humidity goes up, hair stretches. In fact, from 0 to 100 percent humidity, a 10-centimeter length of hair may change by as much as 0.25 centimeter.

The **sling psychrometer** is a weather instrument consisting of two side-by-side thermometers. The bulb of one of the thermometers is wrapped in a sleeve, which is moistened with water. The other thermometer bulb stays dry. The psychrometer is swung rapidly in the air. The relative humidity determines how fast water evaporates from the sleeve (and causes additional cooling). Humidity is calculated from the difference in temperature between the wet-bulb and dry-bulb thermometers.

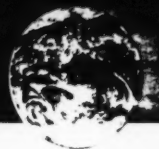


Answers to "Building a Hygrometer"

1. To absorb water from the air.
2. The needle rose.
3. A change in the amount of water absorbed within the blotting paper.

Activity: Building a Hygrometer

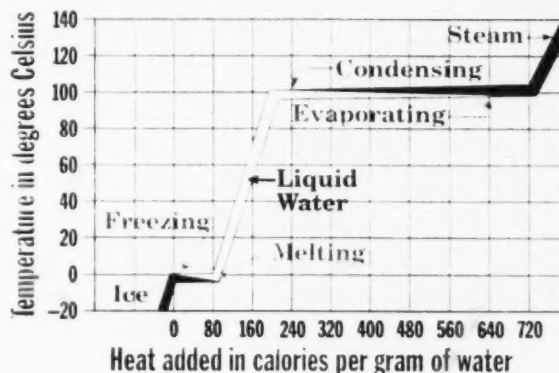
Distribute copies of the Activity Sheet. The student-built hygrometer is another tool that can measure humidity. It depends on a delicate balance. When the blotting paper is



exposed to high humidity, it absorbs water. The extra water increases the paper's mass, and the balance changes. When moisture evaporates from the paper, its mass decreases and the balance needle moves in the opposite direction.

Condensation

Review the phases of water as it changes from solid to liquid to gas. Examine the relation between phase change and gain or loss of heat. Have students think about the processes of freezing, melting, evaporation, and condensation. If appropriate, present the double-plateau graph showing water's phase changes at atmospheric pressure as heat is added.



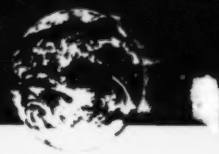
Demonstration (Technology Connection)

Display a distillation device. Identify its parts and explain the relations among heat, the parts, and phase change. Students should understand that during distillation, liquid water turns to gas (water vapor). As it escapes the liquid phase, it leaves behind particulates and solutes such as salts. The gas is then cooled (most often by a water jacket). As it cools, it condenses to a liquid. Residues are left behind, and the remaining liquid is pure water. You can also demonstrate distillation by holding a cold glass in steam from boiling water. The condensate will be distilled water.

Distillation is used to make fresh water in many arid areas (for example, areas in the Middle East) that have an ample supply of saltwater.

Uncovering Misconceptions

Explain to students that water vapor is invisible. The cloud they observe over boiling water is not water vapor, but a cloud formed by tiny droplets of liquid water that have condensed in the cooler air. If you hold a cold glass in the clear area above boiling water, vapor will condense on it, showing that water vapor is invisible.

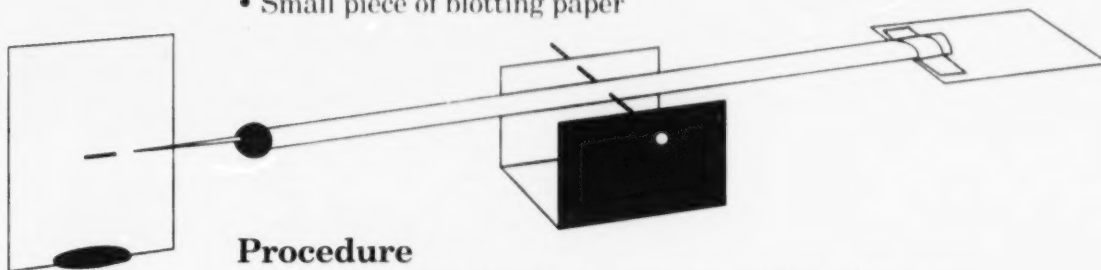


Building a Hygrometer

A hygrometer is an instrument used to measure the moisture content of air. **Humidity** is a measure of the moisture content. There are several types of hygrometers; the instrument you will build is based on a sensitive balance.

Materials

- Big pin
- Straw
- Toothpick
- Tape
- Pen or pencil
- Shallow pan
- Scissors
- Modeling clay
- 2 small index cards
- Small piece of blotting paper

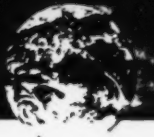


Procedure

1. Carefully insert the pin through the middle of the straw.
2. Cut out a square of blotting paper about 5 cm on a side.
3. Use tape to attach the paper to one end of the straw.
4. Fold an index card into a U-shaped support, as shown.
5. Place the straw on the support so that the two upright edges of the card hold the pin.
6. Place a small lump of clay over the other end of the straw. Insert a toothpick into the clay to make a pointer needle.
7. Adjust the amount of clay to balance the straw.
8. Use another small lump of clay to make a stand for the second index card. Place this card behind the needle. Mark the position of the needle on the card.
9. Place a pan of warm water beneath the blotting paper.
10. Wait 10 minutes. Observe and mark the new position of the needle.

Questions

1. What is the function of the blotting paper?
2. What happens to the needle when the warm water is introduced?
3. What would an upward or downward movement of the needle suggest?



Dew Point

The **dew point** is the temperature at which air is saturated with water vapor. If the temperature drops below the dew point, water molecules leave the gas phase and become either liquid or solid.

At night, the temperature often drops below the dew point. If the temperature is above freezing, water vapor condenses, forming tiny droplets of water called **dew**. If it is below freezing, **frost** forms.

Cloud Formation

As a mass of warm air rises, it begins to cool. When its temperature reaches its dew point, water vapor in the air mass begins to condense. Droplets of water form around tiny particles of chemicals, dust, and salt. These particles are called **condensation nuclei**. The droplets are so small that they are kept aloft by even slight air currents. When enough droplets form, they appear as a large mass we call a **cloud**.

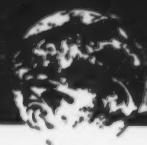
Activity: Airborne Particles

Collect airborne particles (ash, soot, micrometeorites, and dust) on greased slides and observe them under a magnifying glass or microscope. Have students gather a collection that includes samples from different parts of town, under different wind conditions. The slides should be carefully labeled.

Types of Clouds

Clouds are named by appearance. **Cirrus** are high, thin clouds made of tiny ice crystals. **Stratus** are a low layer of clouds that may or may not touch the ground. Any precipitation falling from these clouds will be light. **Cumulus** clouds are the puffy, white clouds that often form during the day at any season. **Fog** is a cloud that is at ground level. All of these clouds form when air is cooled below its dew point.

TEACHER'S NOTES : AIR HUMIDITY, CLOUDS, AND RAIN



Precipitation

When water droplets in a cloud become big enough, they can no longer be kept aloft by air currents. They fall to the ground as precipitation. Forms of precipitation include rain, snow, freezing rain, sleet, and hail.



Stratus cloud.

Discussion: Cloud Seeding (Critical Thinking Exercise)

Have students discuss cloud seeding as a means of increasing precipitation. Cloud seeding is done when clouds that might make rain are present. Crystals of silver iodide are introduced into the atmosphere. The crystals serve as condensation nuclei and encourage the formation of rain in the clouds. Remind students that cloud seeding may shift the location of rainfall, however, and downwind regions sometimes receive more rain.



Cumulus cloud.

Activity: Observing Condensation

Fill a clear glass with water and add a few ice cubes. Add several drops of food coloring and stir. After several minutes, observe the exterior of the glass. Ask students what they observe on the glass's exterior. Then ask where the water on the glass's exterior came from and how they can infer this.

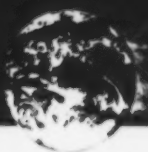


Activity: Making Clouds

Distribute copies of the Activity Sheet. Explain that salt particles in air are condensation nuclei and make haze more likely, which is why haze is more common near the ocean. Dust, smoke particles, and other material in the air, including acid particles involved in formation of acid rain, can also be condensation nuclei. That is one reason polluted air often appears hazy.

Answers to "Making Clouds"

1. The formation of a cloud.
2. The cloud disappeared.
3. To produce condensation nuclei.



Making Clouds

Materials

- A match
- Incense cone
- Rubber band
- Warm water
- Scissors
- Small glass jar (about 7 cm diameter)
- Large balloon (twice the jar's diameter, uninflated)

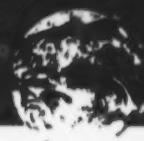
Procedure

1. Cut the balloon in half. Make sure the piece without the opening will be able to stretch across the mouth of the jar, as shown in the diagram, to produce an air-tight seal.
2. Add warm water to the jar until it reaches a depth of about 1 cm.
3. Introduce smoke from a glowing incense cone into the space above the water.
4. Stretch the balloon piece over the jar's mouth and secure it with the rubber band.
5. Being careful not to break the seal or the balloon, pull the balloon piece outward. Record what you observe.
6. Carefully push the balloon piece inward. Record what you observe.

Questions

1. What do you observe when the balloon piece is pulled outward?
2. What happens when you push the balloon piece inward?
3. Why was smoke introduced into the jar?





Acid Fog, or Smog

Because fog occurs at ground level, it traps pollutants. When acid-forming gases rise into fog or low-lying clouds, their chemical components quickly react with water to produce an acidic fog, or smog. This destructive cloud bathes the ground in an acidic mist. Acid fog can be much more acidic than acid rain.

The term **smog** comes from the words "fog" and "smoke." Smog can produce deadly results. During sustained smog conditions, increases in hospitalizations and deaths from breathing and lung problems are common. The pollutants associated with smog include emissions from internal combustion engines, particularly from older cars. While emission controls, catalytic converters, more efficient engines, and cleaner fuels have reduced release of pollutant gases by individual engines, the increased number of vehicles in the United States has resulted in increased release of these gases.

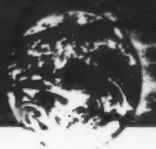
Urban areas experiencing smog may curtail emissions by temporarily closing industries and restricting vehicular traffic. In forested regions, smog takes a different toll. It bathes vegetation in an acid solution, causing leaf spotting and decay. As the acid eats away at exposed plant parts, photosynthetic efficiency drops, resulting in a rise in plant mortality.

Smoggy Inversions

An atmospheric condition known as a **temperature inversion** can compound smog effects. During an inversion, a mass of warmer air lies atop the air mass on the ground. The upper air restricts movement and dispersal of polluted surface air, so pollution increases. Geography plays an important role in inversions, as in the Los Angeles basin or in Johnstown, Pennsylvania.

Extension: Black Fog

In 1952, an inversion in London trapped fog that became rich in pollutants from burning coal. More than 4,000 deaths were attributed to this deadly smog, nicknamed "black fog." Students can look at the Black Fog in the context of the industrial revolution and subsequent emissions controls.



Interpreting Weather Maps

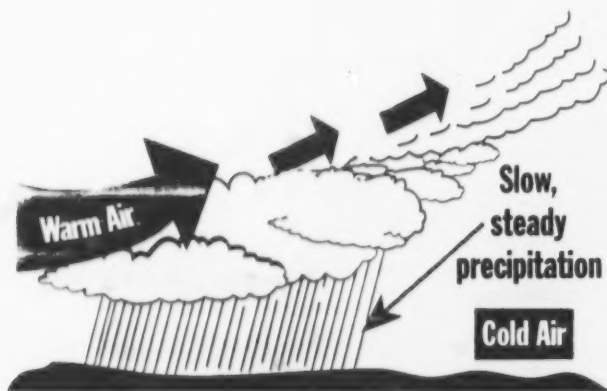
Obtain weather maps from local, regional, and national newspapers. Compose a master set of several maps that illustrate different weather conditions. Distribute copies of the maps to classroom groups. Have students compare and contrast the ways different maps illustrate the same weather. Ask them to design their own symbols to use on a daily classroom weather map.

Air Mass

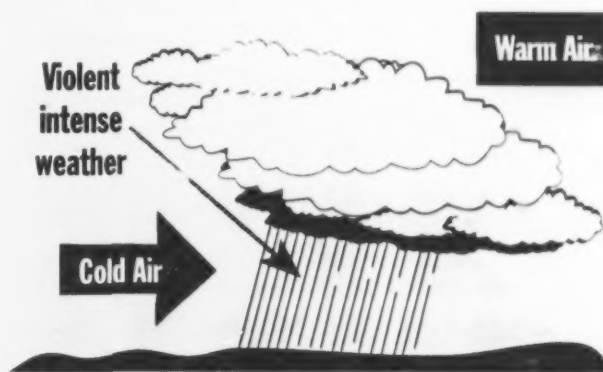
An **air mass** is a large volume of air in the troposphere that has uniform characteristics, including temperature (warm air mass), or humidity (dry air mass).

Fronts

Fronts are boundaries where air masses meet. Dramatic changes in weather occur at boundaries. At a **cold front**, cool, dry air slips beneath a warm air mass. Because cool air is heavier than warm air, it sinks. As the cool air moves forward, it acts as a wedge, rapidly lifting the warmer air. This condition can produce heavy precipitation and strong wind gusts. At a **warm front**, warm air gradually climbs over a cold air mass. The warm air is less dense and tends to rise above the heavier cool air mass. A warm front can produce steady precipitation. At a **stationary front**, neither air mass moves and intermittent rain often results.



Warm Front



Cold Front

**Activity: Interpreting a Weather Map**

Supply the class with copies of the Activity Sheet. Display the color overhead transparency of these illustrations. Compare and contrast the information available on a satellite image and a newspaper weather map. Have students use the image and map to interpret the weather for several locations. If possible, obtain a sequence of weather maps and show them to the class. Have students identify and follow various atmospheric features.

Extension: Weather Reporter

Divide the class into student groups of four. After interpreting the weather map handout, have students write the script for a weather report. The content should reflect the information inferred from the activity. If possible, encourage the groups to produce a videotape of their weather reports.

Extension: On-Line Connection

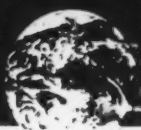
Explain that on-line computer services often post current weather information. In addition to standard forecasts, satellite weather maps can be downloaded. Students may wish to examine several maps and identify weather features captured by satellite imagery.

Extension: Violent Weather, Human Effects

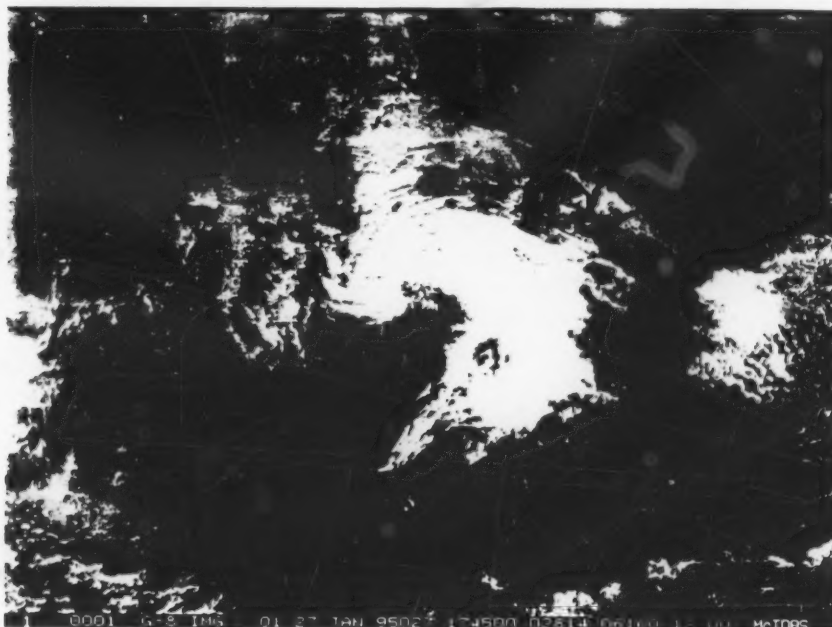
Have students research violent weather patterns, like thunderstorms, hurricanes, blizzards, tornadoes, and chinook (or foehn) and Santa Ana winds. Students should compare and contrast the types of weather, and identify similarities and differences among the weather systems. Have students research effects of violent weather on humans.

Extension: Hurricane Watch

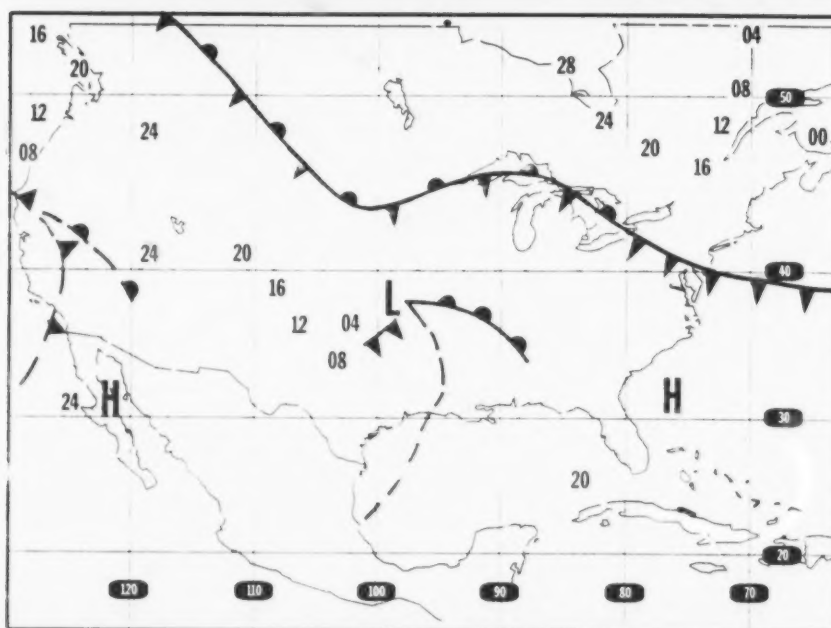
Contact a local weather station to obtain a source for hurricane tracking maps. Such maps allow students to track a storm's center using longitude and latitude. You may also wish to have students download hurricane maps from on-line services. (See also the Information Sheets on Hurricane Hugo.)



Interpreting a Weather Map



These graphics show a satellite image in visible wavelengths centered on the U.S. at 12:45 pm Eastern Standard Time, January 27, 1995, and the corresponding weather map.

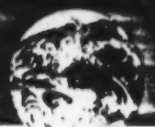


Typical sea level pressure is 1000 millibars (mb). Meteorologists use the convention that 00 represents 1000 mb. Example: 1024 mb is represented by the 24 isobar; 998 mb is represented by the 98 isobar.

—▲— low front.

- - -▲- - - high front.

- - -▲- - - stationary front.

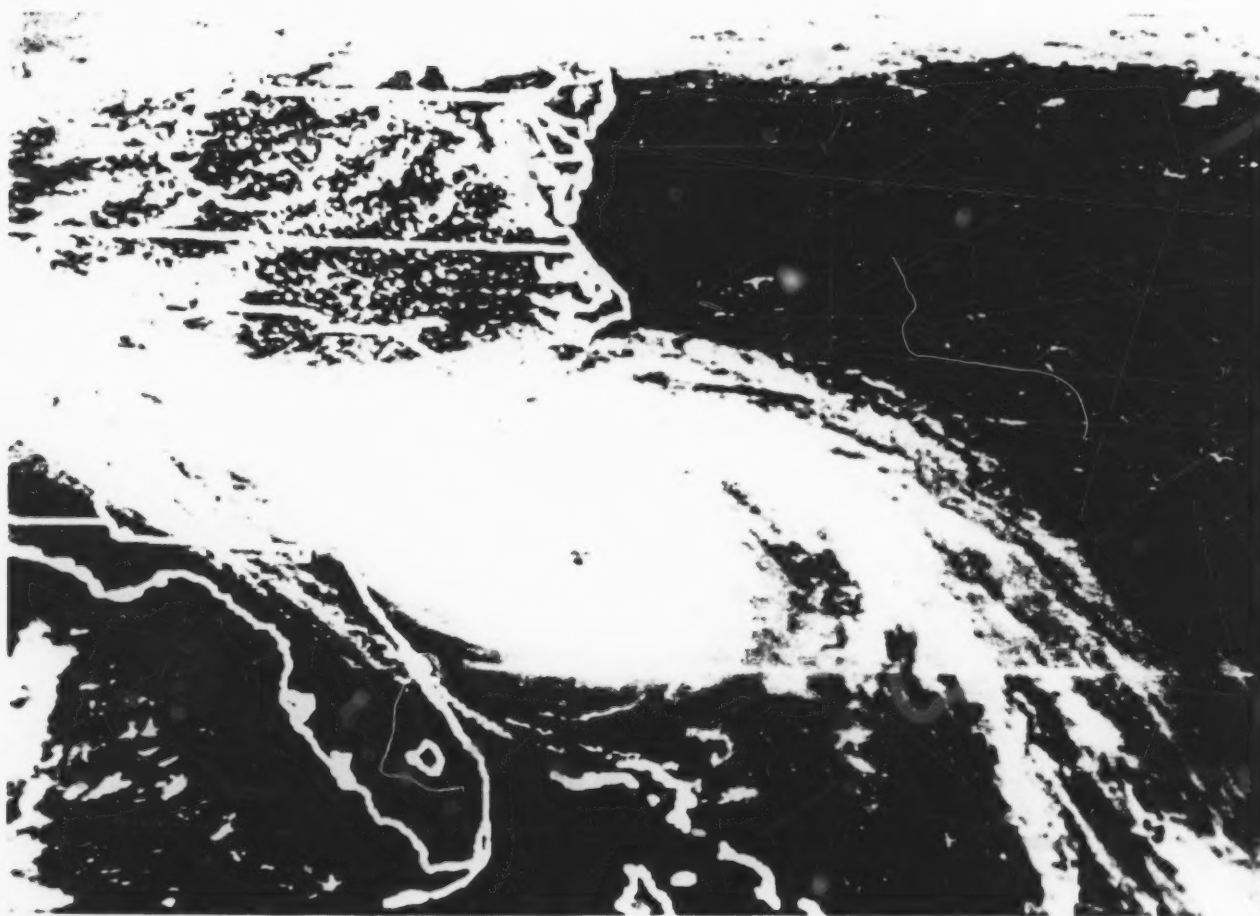


Visible Image of Hurricane Hugo

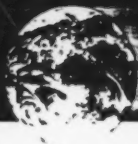
The picture below is an image in visible light of Hurricane Hugo poised offshore of Charleston, South Carolina, at 1:31 p.m. Eastern Standard Time, September 21, 1989. It was taken by a geostationary satellite operated by NOAA. Note the well-defined eye and surrounding intense thunderstorms.

On the cover of this book is an enhanced image (infrared wavelength) of Hurricane Hugo taken at the same time and place.

Hugo was an impressive and powerful hurricane. Several days before this image, on September 15, reconnaissance aircraft measured flight-level winds of 305 kph (190 mph)



Hurricane Hugo prepares to strike Charleston, South Carolina.



when the storm was still several hundred miles east of the Leeward Islands. Surface winds at the same time were estimated at 160 mph (255 kph).

The storm weakened only slightly during its subsequent west-northwest journey, and was still very strong and dangerous when it made landfall near Charleston at about midnight, September 21. Winds at landfall were estimated at 140 mph (225 kph), and the central sea level pressure was measured at 934 mb (27.58 inches of mercury).

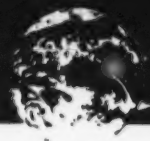
Hugo caused substantial damage during its path of destruction through the southeastern U.S., and its final cost of \$7,000,000,000 made it the most expensive hurricane to strike the country, up to that time.

Infrared Image of Hurricane Hugo (Cover)

Infrared nonenhanced satellite imagery is sensitive to temperature, and shows colder, cloud-top temperature in brighter shades of white. Warmer, low clouds or ground temperatures are indicated by darker shades of gray.

Using today's technology, it is quite easy to color-enhance infrared imagery, with the user specifying the color each range of temperatures represents. In this enhancement, red colors indicate the coldest temperatures, while dark blue or black hues indicate the warmest temperature.

The atmosphere usually becomes colder with increasing elevation; the intense and tall thunderstorms surrounding Hugo appear red, while low clouds and clear ocean and land areas appear blue and black.



Two Global Issues

Explain to students that our atmosphere faces challenges other than acid precipitation. Other global dilemmas include ozone depletion, heavy-metal pollution, and greenhouse warming.

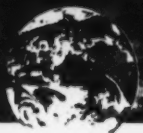
This section focuses on ozone depletion and greenhouse warming. Both issues involve delicate balances that are threatened by contemporary human behavior. Both involve pollution on a global scale. Survey the class's knowledge of these dilemmas. Introduce each problem as an extension of what students have learned about the atmosphere and how it works.

Ozone

Ozone is a strong-smelling, pale blue gas that is poisonous to humans. Unlike diatomic oxygen gas (O_2) ozone has molecules made up of three atoms of oxygen (O_3). Ozone occurs throughout the atmosphere, but 90 percent of all ozone is found in the stratosphere. It is most concentrated in the middle of the stratosphere, from 20 to 50 kilometers above the ground. This concentration is known as the **ozone layer**. The ozone layer shields living things from the Sun's **ultraviolet radiation (UV)**, an excess of which is harmful. (Some UV is necessary to humans.). Almost all UV radiation from the Sun that reaches the atmosphere is absorbed by the ozone layer.

Ozone forms naturally in the stratosphere. Oxygen (O_2) in the stratosphere absorbs the Sun's energy in the shorter wavelengths of UV radiation. The extra energy separates the two atoms in oxygen molecules. The free atoms recombine with other oxygen atoms to form ozone (O_3).

The ozone does not build up endlessly. Energy from longer wavelengths of UV radiation breaks down ozone molecules to produce oxygen. This process is greatly assisted by the presence in the high atmosphere of substances such as nitrogen oxides, which act as catalysts. The processes of ozone production and destruction are finely balanced.



Ozone Depletion

The ozone layer is an important shield protecting life on Earth. Our understanding of this critical layer began several decades ago when supersonic passenger aircraft such as the Concorde began to fly high above the altitudes of traditional jet aircraft. Scientists were concerned about the effects of exhaust gases released in the upper atmosphere. As they studied the problem, they uncovered evidence that air pollutants released at Earth's surface may cause as much ozone destruction as high-altitude emissions. They found that gases such as nitrogen oxides, bromine, methyl chloride, and carbon tetrachloride could act as catalysts in breaking down the ozone molecule. The **chlorofluorocarbons** (CFCs), artificial compounds that began to be made in quantity in the 1930s, seemed to be the most damaging group of gases.

CFCs are broken down very slowly in the atmosphere by solar radiation. This process releases reactive chlorine atoms. In the stratosphere, in a series of steps, chlorine changes ozone into atomic and diatomic oxygen. Research suggests that a single chlorine molecule can destroy 10,000 ozone molecules before being captured in a stable molecule with hydrogen or nitrogen.

In most of the stratosphere, 99 percent of chlorine is in stable compounds. Over Antarctica, however, clouds of ice crystals form in the very cold air. Some are water ice crystals, others are frozen sulfuric acid aerosols with a nitric acid coating. On the crystal surfaces, the stable compounds release chlorine in forms easily broken apart by sunlight. When the Sun appears after the long polar night, about 99 percent of the chlorine is freed as atomic chlorine, which destroys ozone, creating an area of very low ozone concentration called the ozone hole.

CFCs are being phased out worldwide and are no longer put in aerosol cans, but they still are found in older refrigerators and air conditioning units and are used in some manufacturing processes. Federal and state regulation and international agreements are limiting CFC use, manufacture, and release. Perhaps the biggest success in limiting CFC use comes from the manufacture and use of alternate refrigerant gases that have little or no effect on



the ozone layer. CFCs have a long lifetime, however, and scientists say that they will affect the ozone layer until at least the year 2020.

Ultraviolet Radiation Damage to People

The lower the ozone concentration in the stratosphere, the more UV radiation reaches Earth's surface. Although some UV is necessary and beneficial in helping produce vitamin D, it is thought to be a cause of skin cancer, which kills about 10,000 people each year in the United States. The Environmental Protection Agency estimates that a decrease in stratospheric ozone concentration of 1 percent, and the consequent rise in UV radiation, would lead to an increase of 5 percent in nonmelanoma skin cancers in the United States and a 1 percent increase in deaths from skin cancer. UV radiation reduces the effectiveness of the body's immune defense system and lowers resistance to diseases such as cancer, herpes, and hepatitis. It also causes cataracts, which affects nearly 30 million people worldwide.

Ultraviolet Radiation Damage to Plants

UV radiation can damage plants and marine life, thus affecting food supplies. Only a limited number of crop species have been tested for sensitivity to UV radiation, but about two thirds of them have shown signs of damage. Yields of some varieties of soybean are reduced by one quarter when UV exposure is increased by 25 percent.

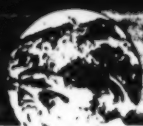
Ultraviolet Radiation and Mutations

When UV energy strikes a cell, it may be absorbed by some of the components of a DNA molecule possibly altering the genetic code. Such an alteration is called a **mutation**. Mutations can be good or bad. Some mutations produce disorders, including cancer. Other mutations produce beneficial characteristics that make possible the continued evolution of life on this planet.

Answers to "The Ozone Hole Fact Versus Inference"

1. Fact
2. Fact
3. Inference
4. Fact
5. Inference

Teacher's Notes continue on page 50.



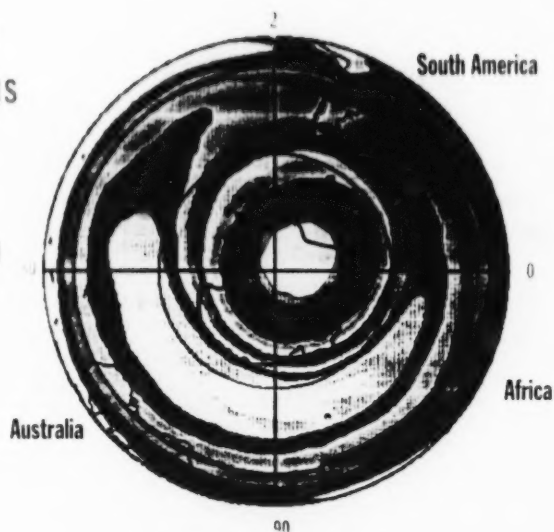
The Ozone Hole



October 1979

Total Ozone
Monthly Means

Antarctica is outlined
in center of maps

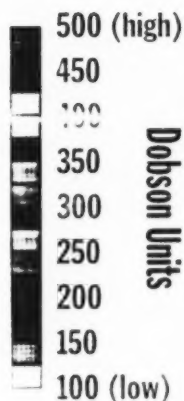


October 1994

Antarctic Ozone

The images on this page and on the color transparencies are made from measurements taken over Antarctica throughout each October since 1979 using a Total Ozone Mapping Spectrometer (TOMS). TOMS is an instrument that senses the particular wavelengths of radiation given off by the ozone molecule. It is mounted on a polar-orbiting satellite.

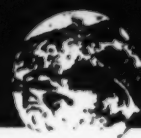
The color coding of ozone levels, measured in Dobson units, ranges from white (100 units) through shades of purple (100-200), blue and green (200-300), green and orange (300-400), and orange and red to black (400-500 units). Each small square on the color bar represents 25 units. The darkest shades of color appear black in these black and white images.



Fact Versus Inference

Procedure: Study this page and the color transparencies. Using only the information from the TOMS images, identify each of the following statements as a fact or an inference.

1. The concentration of stratospheric ozone in October over Antarctica (the continent outlined in the middle of each image) has decreased since 1979.
2. The area covered by the ozone hole has increased since 1979. (The hole is the zone over Antarctica in dark green, blue, purple, and white.)
3. Chlorine released from the breakdown of CFCs created the ozone hole.
4. In 1994 the hole extended over the southern tip of South America.
5. The ozone hole did not exist before the release of CFCs into the atmosphere.

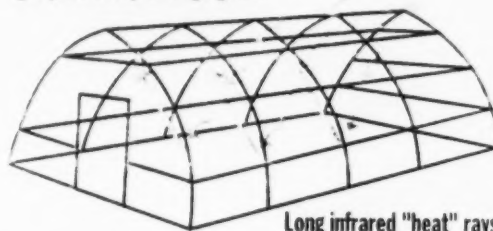


Activity: The Ozone Layer

The ability to distinguish a fact from an inference is an important skill that a scientist must perfect. This activity gives students practical experience in observational skills and in differentiating between an inference and a fact.

Display the two overhead TOMS color transparencies from the envelope and distribute the Activity Sheet. Explain that the colors are color enhancements that allow visualization of variations in the ozone concentration in the stratosphere. Have students interpret what they see.

Short wavelengths of visible light pass easily through glass.



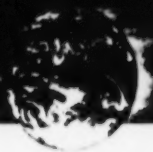
Long infrared "heat" rays are trapped inside the greenhouse.

Greenhouse Warming

The atmosphere is a clear blanket surrounding Earth. About 50 percent of the radiation from the Sun passes through this blanket. When it strikes Earth's surface, it is either reflected or absorbed. The absorbed energy is changed to heat and reradiated at infrared wavelengths by the surface. Most heat energy remains trapped in the atmosphere because clouds and gases like water vapor, carbon dioxide, and methane absorb and reradiate it back toward earth. This continuous warming of the atmosphere is called the **greenhouse effect**.

For billions of years, the greenhouse effect has moderated the temperature of our planet's atmosphere, maintaining a range that could support life. Without this natural heating, our planet would be too cold for life as we know it.

Since the industrial revolution (middle of the 19th century), the quantity of certain greenhouse gases has increased. These gases include carbon dioxide, methane, nitrous oxide, and, since the 1930s, CFCs and now their substitutes. Scientists are studying whether this increase, called the **enhanced greenhouse effect**, is producing a global warming trend. Weather records



indicate that the average temperature at Earth's surface has increased about 0.5 degree Celsius during the past century. Although this observed temperature increase may be a normal variation, many people are concerned that it may be caused by increased levels of greenhouse gases and that it will continue.

Sulfur dioxide is not a greenhouse gas. Its atmospheric products form haze and act as condensation nuclei that form clouds. The increase in haze and clouds from increasing SO_2 production increases the amount of solar radiation reflected back into space before it ever reaches Earth's surface.

Activity: Greenhouse Warming

This experiment shows that the greenhouse effect is not restricted to glass. If there is sufficient sunlight, the transparent window trial should result in a more pronounced rise in temperature than the translucent one. The box should be tilted so the Sun's rays are perpendicular to the bottom of the box and the thermometer does not receive direct sunlight. If there is insufficient sunlight, a clamp lamp or overhead projector lamp can provide enough light for the activity.

Resources

Matthews, Samuel W. (1990, October). Under the Sun—Is Our World Warming? *National Geographic*, 178 (4), 66–99. Special Issue: Physics and the Environment. (1994, November). *Physics Today*, 47 (11).

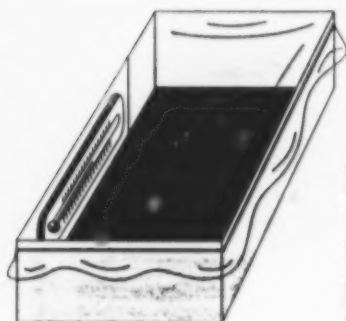
Answers to "Greenhouse Warming"

1. The box temperature for the plastic-wrap trial was the highest.
2. Different amounts of light reached the box's interior, and different amounts of light and heat were able to leave the box.
3. The plastic wrap produced the highest temperature because it let in the most light but retained the heat.
4. The temperature rise still occurs when you substitute translucent wax paper for transparent plastic wrap, but less light enters the box. Depending on the amount of sunlight, you may or may not notice a difference in temperature between the plastic-wrap and translucent-wrap trials.



Greenhouse Warming

Have you ever been in a greenhouse? If so, you know that greenhouses become warm during the day when sunlight comes through the window glass. When the light strikes the objects inside the greenhouse, the objects absorb a small bit of the light's energy. This energy change means that energy is reradiated by the objects in the form of heat, or infrared radiation, which remains trapped inside the greenhouse because heat can not pass through glass the way light does.



Materials

- Shoe box
- Plastic wrap
- Scissors
- Thermometer
- Tape
- Wax Paper

Procedure

1. Tape a thermometer to an inner side of a shoe box (not the bottom). Wait several minutes. Record the starting (room) temperature.
2. Place the box in direct sunlight and tilt the box to face the Sun. Do not let sunlight strike the thermometer directly. Wait 30 minutes, and record the temperature.
3. Allow the box to cool to room temperature.
4. Cover the box with its lid, and again place the box in direct sunlight and tilt the box. After 30 minutes, open the box and record the inside temperature.
5. Again, allow the box to cool to room temperature.
6. Now cover the top of the box with a sheet of plastic wrap. Secure the wrap with tape.
7. Place the box in direct sunlight and tilt the box so the sunlight streams in through the clear plastic wrap. Do not let sunlight strike the thermometer directly. After 30 minutes, record the inside temperature.
8. Predict whether you would observe a greenhouse effect using a translucent cover. Then construct a box top of wax paper and repeat the activity.

Questions

1. How do the temperatures of the four trials compare?
2. What causes the differences in the temperatures you recorded?
3. How does a plastic-wrap cover affect the results?
4. How does a translucent wax-paper cover affect the results?

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